

FIRST DISCOVERY OF AN ULTRA-REFRACTORY NODULE IN AN ALLENDE FINE-GRAINED INCLUSION.

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Introduction: Fine-grained inclusions (FGIs) are considered to be of condensation origin judging from their fine-grained texture and the Group II REE pattern typically found in FGIs [1]. Group II REE pattern is characterized by depletion of HREE (except Tm) relative to LREE and depletion of the least refractory Eu and Yb, suggesting condensation from a fractionated (HREE-depleted) gas. However, its counter part, an ultra-refractory component is rarely found in refractory inclusions [2]. We report here the first discovery of an ultra-refractory (UR) nodule as a part of a FGI in Allende (CV3) meteorite. This FGI, named AFG-1, therefore would have important information on the REE fractionation, or gas/dust separation, at very high temperatures.

Texture and mineralogy: The total size of AFG-1 is about 5mm x 5mm. It consists of many nodules of 100-800µm in size (Fig.1). Each nodule is surrounded by diopside rim of a few µm in thickness. Nodules contain many cavities, suggesting they formed from sintering of fine-grained minerals and were not subjected to total melting. Nodules are spinel-rich as a whole but two different lithologies are recognizable: Fe-poor spinel islands and Fe-rich spinel regions. Each nodule contains one or a few Fe-poor spinel island(s) of typically 20-50µm in size. It consists of Fe-poor spinel (FeO=0.5-1wt%), perovskite (a few µm in size) and fassaite. It occupies about a few to ~10% of each nodule. Fe-rich spinel region occupies >90% of the total area. It consists of Fe-rich spinel (FeO~17wt%), fassaite, nepheline and sodalite. The latter two phases were probably an alteration product of melilite and/or anorthite. Occasionally small amount of melilite and anorthite are observed in some nodules.

Nodule A is located almost in the center of AFG-1. A half of Nodule A, named "Hendrix" (Fig.2), consists only of a large Fe-poor island (150µm x 200µm), though its FeO content (FeO=1.5-2 wt%) is slightly higher than the other Fe-poor spinel islands. "Hendrix" is mineralogically and chemically different from any other Fe-poor spinel islands in its ultra-refractory (UR) nature. Spinel is one of the most dominant phases in "Hendrix". Perovskite (~10µm) is also an abundant

phase in the core of "Hendrix" and is enriched in ZrO₂ (1.4-4.9 wt%) and Y₂O₃ (1.1-4.6 wt%). Calcium-rich pyroxene abundantly occurs with perovskite and spinel in the core and as rim of "Hendrix". In the core, the pyroxene is fassaite with 20.6-30.2 wt% Al₂O₃, 9.6-13.2 wt% TiO₂, 2.0-5.7 wt% Sc₂O₃ and 0.5-3.9 wt% ZrO₂. High contents of Sc and Zr characterize the pyroxene in "Hendrix", and Sc/Zr ratio follows the solar abundance ratio. On the other hand, Sc₂O₃ and ZrO₂ contents of the pyroxene in the rim decrease from inner to outer parts, 5.5 to 0 wt% and 3.9 to 0 wt%, respectively. Tiny ZrO₂ phase (a few µm) is encountered in close association with perovskite. Fine-grained metal (≤a few µm) occurs within perovskite, fassaite and spinel. They contain 1.6-17.8 wt% Ru, 1.7-27.9 wt% Os and 5.3-25.8 wt% Ir. All these mineralogical features are consistent with the ultrarefractory REE patterns (see below).

Conditions for REE Analyses: Abundances of Ba, REEs and Hf were determined using an ion microprobe (CAMECA ims-6f, University of Tokyo). An energy filtering method, similar to that described in [3,4], was used for the REE analyses. An O⁻ primary beam, 15-30µm in diameter, 22.5keV impact energy with a beam intensity of 1-3nA, was used for the analyses. Positive ions were accelerated at 10kV. All the peaks between masses 133 to 185, including Ba, all REEs and Hf, were measured at low mass resolving power (~300). An energy offset of 60V, with a 30V energy window, was applied to reduce the effects of complex molecular interferences and the analyzed peaks were mathematically deconvolved into atomic (M⁺) and oxide (MO⁺) ions, where M represents Ba, REEs or Hf. Sensitive factors relative to Ca⁺ and oxide production ratios (MO⁺/M⁺) for Ba, REEs and Hf were predetermined using synthetic glass standards and used for the calculation.

REE Abundance Patterns: CI-normalized abundance patterns of Ba, REEs, and Hf in selected positions of "Hendrix" are shown in Fig.3. All the analyzed positions show enrichment in HREE relative to LREE with negative Eu and Yb anomalies. Even Pos#7 (rim pyroxene) shows slight enrichment in

HREE. However, since the analyzed area of Pos#7 covers both fassaitic and diopsidic pyroxene, the REE signature may reflect inner UR signature carried by fassaitic pyroxene. The highest enrichment of HREE ($\sim 10^4 \times \text{CI}$) is observed in Pos#15 (perovskite is the major carrier of REEs for this point). The HREE/LREE enrichment factor varies from position to position, suggesting that each position contains variable amount of UR component. Largest depletions in Eu and Yb are found in perovskite (and perovskite-bearing positions).

The observed REE patterns in “Hendrix” are more or less similar to those found in an inclusion from Efremovka [2]. However, since “Hendrix” has never been melted, the observed REE patterns in “Hendrix” must reflect more closely the original UR patterns. “Hendrix”, therefore, is a unique example of the UR component trapped as a part of a FGI and serves as a unique source of information on the REE fractionation, or gas/dust separation, occurred in the solar nebula at the highest temperature stage.

References: [1] Hashimoto A. et al. (2001) *Meteoritics & Planet. Sci.*, 36, A75-A76. [2] El Goresy A. et al. (2002) *GCA*, 66, 1459-1491. [3] Zinner E. and Crozaz G. (1986) in *SIMS V*, Springer, NY, 444-446. [4] Fahey A. J. (1988) PhD Thesis, Washington University.

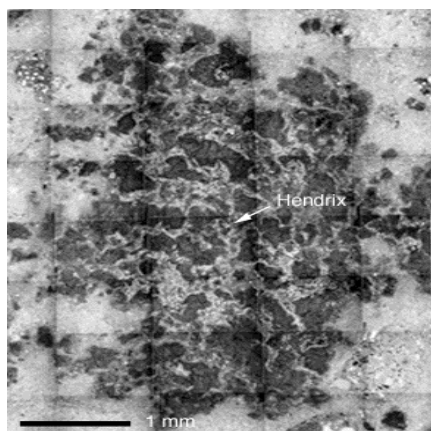


Fig.1 A back-scattered electron (BSE) image of AFG-1. Nodule A with “Hendrix” is located almost in the center of this FGI.

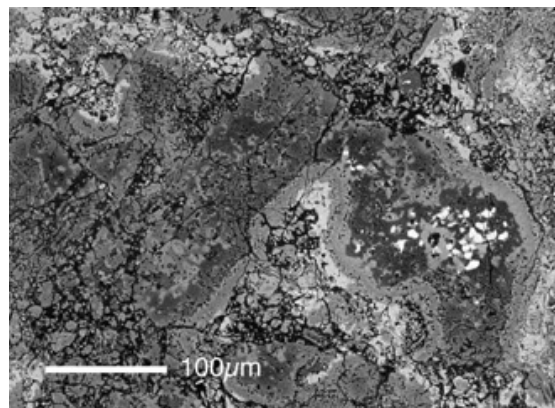


Fig.2 A BSE image of Nodule A. The right half of Nodule A is “Hendrix”. Dark area is Fe-poor spinel, bright spots are mostly perovskite with some ZrO_2 grains and tiny ($\leq a \text{ few } \mu\text{m}$) refractory metal grains (mostly invisible in the figure). Grey part, both in the rim and the core of the nodule, is Ca-rich pyroxene. Light gray part outside the rim is hedenburgite.

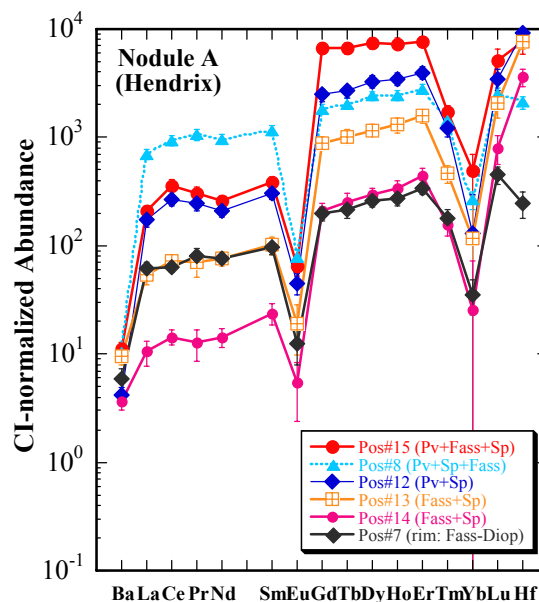


Fig.3 Abundance patterns of Ba, REE and Hf in selected positions of Nodule A (“Hendrix”).